and the winds mostly from the north. Heavy rain fell in California, but there was no especially well-marked depression. On January 1 the depression was well marked. In 24 hours there had been a fall of nearly half an inch in pressure and the rain area covered most of California, all of Nevada, all of Arizona, and most of Utah. The significant feature of the pressure distribution, however, in my judgment, was the appearance of a marked high over Montana. This appears to have blocked the eastern passage of the low and for a period of 72 hours stormy conditions prevailed with heavy rain turning to snow in the district under consideration. There was an aftermath, so far as California is concerned, in the period of heavy frosts culminating on January 6. On this date during the morning hours more than half of the State experienced temperatures below freezing.

The following special dispatch to the San Francisco Chronicle from Los Angeles, Cal., gives an approximate value of the losses sustained by the citrus fruit growers of the southern counties, due to the heavy frosts of the first decade of January, 1910:

This year's orange crop has been damaged approximately $1,000,000, according to estimates made by reliable growers. Some believe that this amount will also cover the damage to nursery stock and to the coming year's crop, while others figure that the total may be several millions.

As compared with the $35,000,000 valuation of the present crop, this is not a discouragingly large item. Several of the leading growers make the surprising statement that the cold weather brought them more benefit than harm. The frosty weather came just in time to check the growth and hold the oranges to normal size. * * * Deciduous fruit men believe their profits by reason of the cold will be more than the citrus fruit growers' losses.

PRECIPITATION, RUN-OFF, AND EVAPORATION IN THE OWENS VALLEY.

By CHARLES H. LEE, Assistant Engineer, Los Angeles Aqueduct.

The region known as the Great Basin, or District No. 10 of the Weather Bureau, is unique among the great North American drainage areas on account of there being no surface outlet to the ocean for its streams. Generally speaking its climate is arid, the annual precipitation being less than 10 inches over a large part of its area, but in the high mountain ranges forming its eastern and western borders the snowfall is very heavy. The chief rivers of the Great Basin rise in these ranges, receiving their supply directly from melting snow, and flow out into the valleys where they either entirely disappear by evaporation and seepage, or feed saline lakes whose surface fluctuations register the differences of inflow and evaporation. Topographically the region is characterized by narrow isolated mountain ranges with a general north and south trend, between which are broad valleys which have been built up by the accumulation of unconsolidated material from the adjacent mountains. Many of these débris-filled basins are so surrounded and underlaid by the solid rock that they are practically water tight, and where there is a large water supply available the void spaces between the particles of sand and gravel form immense underground storage reservoirs. The region, therefore, affords exceptional opportunity for the study of the phenomenon of the occurrence of water within a catchment area and losses by evaporation.

It is from one of these valleys receiving the drainage from the most productive of the Great Basin catchment areas, the east slope of the Sierra Nevada, that the City of Los Angeles is at present preparing to obtain its future supply of water. In connection with this project and under the direction of Mr. William Mulholland, Chief Engineer of the Los Angeles Aqueduct, the writer has had an opportunity during the last two years of making a rather complete field study of the Owens Valley as regards precipitation, run-off, and evaporation. There has now been enough data collected to make complete computations and some of the ideas and conclusions which have been developed are herewith presented.

The Owens Valley (fig. 1) has a length from north to south of about 100 miles and a width from crest to crest of the adjacent mountain ranges of from 20 to 25 miles. The Owens River rises at its northern extremity and flows southward through the valley, finally discharging its waters into Owens Lake, a saline body of water typical of the Great Basin. The position of the river channel is not in the center of the valley, but is close to the base of the Inyo Mountains which border the valley on the east. Lying to the west of the river, at an average elevation of 3,900 feet above sea level, is a plain varying in width from 2 to 5 miles and extending, with but one prominent break, from a few miles north of the town of Bishop almost to Lone Pine. The plain is bounded on the west by the toe of the immense accummulation of alluvial débris which has been piled up at the base of the Sierra Nevada by the many streams debouching from its canyons. In general appearance this plain is very different from the desert slopes to the east and west, for it supports a growth of wild grasses over a large portion of its area, and where it is not washed by surface water is more or less crusted with alkali. An examination of the soil shows it to be damp, and in some places quite moist, a few inches below the surface, and test borings encounter water at a depth of from 2 to 8 feet, depending on the time of the year and the local conditions. Two years' observations in a great number of test wells distributed all over the area have shown that the surface of this ground water has periodic fluctuations. About September 20 of each year it is at its lowest level and its highest level is reached about March 20. Its rate of rise and fall is quite uniform unless interfered with by seepage from local surface water and the average amount of fluctuation is 3 feet. It has been found that the wild grasses will not grow nor the alkali appear where the average depth to water exceeds 8 or 9 feet. The significance of this area will be shown later on.

As already stated, between this grassy plain and the steep eastern face of the Sierra Nevada there is a broad desert slope of alluvial material from 4 to 7 miles in width reaching an elevation of from 6,000 to 7,000 feet at its upper edge. From here rises one of the grandest mountain faces on the continent, reaching elevations of from 13,000 to 14,000 feet in a horizontal distance of 3 or 4 miles. Into this granite slope the glaciers and swift-flowing streams of past ages have cut deep canyons, narrow at the mouth and broad in their upper portions, which form the catchment basins of the 40 tributary streams entering the channel of Owens River at more or less regular intervals throughout its length. The bottoms of many of these canyons are choked by glacial deposits and accumulations of slide material which temporarily absorb the melting snows, and thus have a marked regulating effect upon the stream flow. With this general view of the topography and geology of the Owens Valley region, the subjects of precipitation and run-off will be considered.

There are three types of storms yielding precipitation in this region, namely, the great Pacific coast storms which sweep down from the northwest and swing eastward into the Rocky Mountain region, the Sonora storms from the southwest, and afternoon thunderstorms occurring during July and August, which are local in the high mountains. The first of these yields practically all of the water which is effective in replenishing the streams or increasing the underground supply. A topographic factor controlling the distribution of precipitation from these general storms over a large part of California, and particularly the Owens Valley, is the Sierra Nevada. On the western slope there is a consistent increase of precipitation from the Great Valley to about the 4,000- or 5,000-foot level, and from here a slight decrease until the topographic summit is reached. On the eastern slpoe there is a rapid decrease toward the floor of the Great Basin.

In Owens Valley this inequality of precipitation is strikingly apparent, for the snow-clad mountains tower directly above the desert valley, and all storms which cause rain at San Fran-

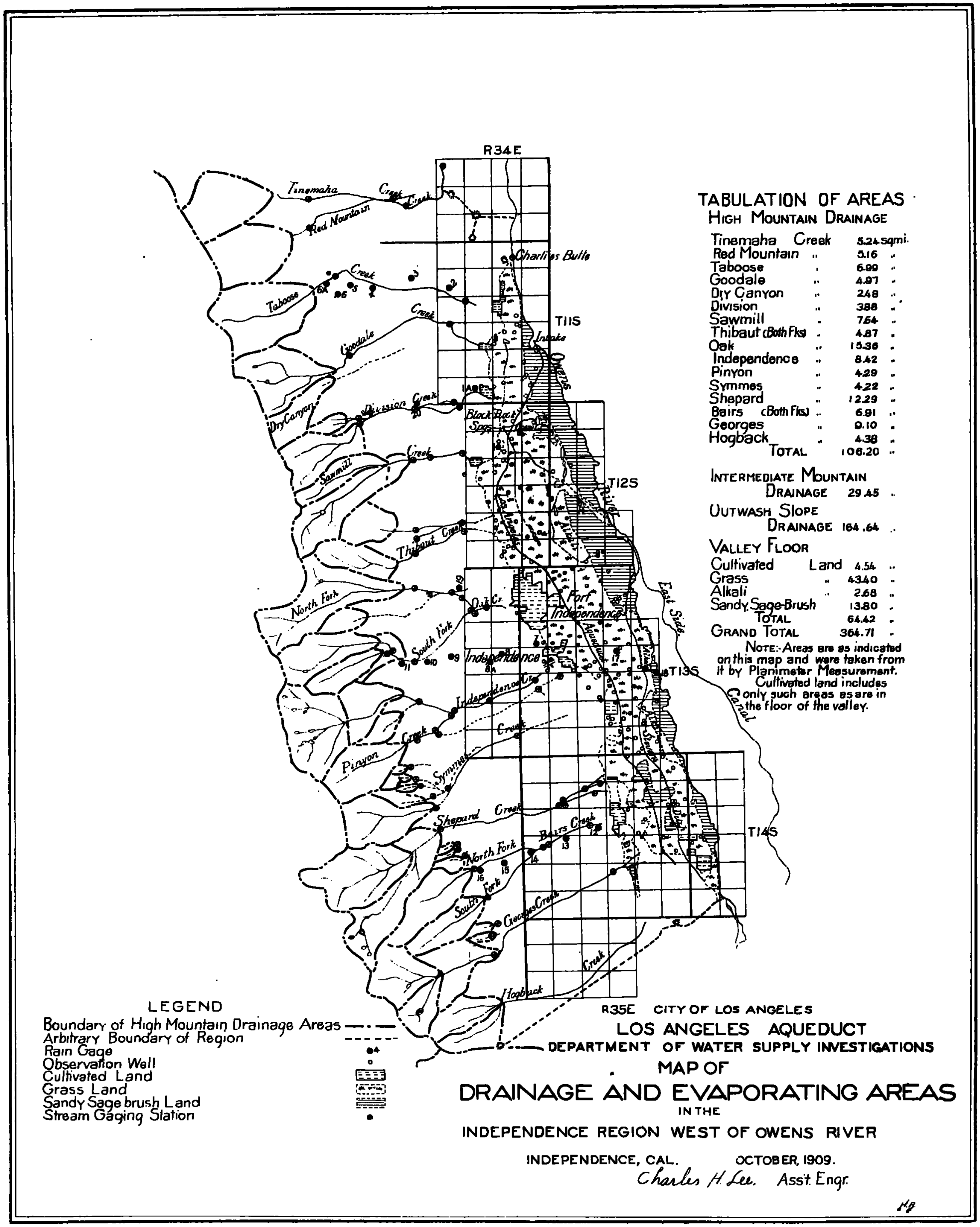
TABULATION OF AREAS
HIGH MOUNTAIN DRAINAGE
Tinemaha Creek 5.24 sq.mi.
Red Mountain 5.16
Taboose 6.99
Goodale 4.97
Dry Canyon 2.48
Division 3.88
Sawmill 7.64
Thibaut (Both Fks) 4.87
Oak 15.36
Independence 8.42
Pinyon 4.29
Symmes 4.22
Shepard 12.29
Bairs (Both Fks) 6.91
Georges 9.10
Hogback 4.38
TOTAL 106.20
INTERMEDIATE MOUNTAIN DRAINAGE 29.45
OUTWASH SLOPE DRAINAGE 164.64
VALLEY FLOOR
Cultivated Land 4.54
Grass 43.40
Alkali 2.68
Sandy Sage-Brush 13.80
TOTAL 64.42
GRAND TOTAL 364.71
NOTE:- Areas are as indicated on this map and were taken from it by Planimeter Measurement. Cultivated land includes only such areas as are in the floor of the valley.
LEGEND
Boundary of High Mountain Drainage Areas
Arbitrary Boundary of Region
Rain Gage
Observation Well
Cultivated Land
Grass Land
Sandy Sage brush Land
Stream Gaging Station
R34E
R35E
T11S
T12S
T13S
T14S
CITY OF LOS ANGELES
LOS ANGELES AQUEDUCT
DEPARTMENT OF WATER SUPPLY INVESTIGATIONS
MAP OF
DRAINAGE AND EVAPORATING AREAS
IN THE
INDEPENDENCE REGION WEST OF OWENS RIVER
INDEPENDENCE, CAL. OCTOBER, 1909.
Charles H. Lee, Ass't Engr.

FIG. 1.

cisco or Fresno always add their portion to the white covering. The storms which extend out over Owens Valley, however, are few and far between, and when they do occur the yield rapidly decreases eastward from the mountains. At the Sierra crest the normal precipitation varies from about 40 inches at the head of Owens River to 25 inches back of Lone Pine. West of Independence it is about 32 inches at the crest, decreases to 15 inches at the upper edge of the outwash slopes (6,500-foot level), and is about 4 inches over most of the valley floor. Above the 6,500-foot level the precipitation is all in the form of snow, and at lower elevations occur as both rain and snow, but all values given represent the equivalent depth of water. Most of this precipitation occurs during the months of October to April. In the mountains there is little melting until summer, and the dry snow is soon blown off the exposed ridges into the canyons, where it accumulates in deep drifts. The only loss from it is by direct evaporation. On the alluvial slopes and the valley floor snow seldom remains unmelted more than 2 or 3 weeks.

The run-off conditions met with in the Owens Valley region are extreme. The mountain drainage basins yield all the precipitation upon them as surface flow, except *possibly 15 or 20 per cent which evaporates;* the alluvial slopes yield absolutely no surface run-off, for every drop of water which is not lost immediately by evaporation sinks into the ground; the valley floor sometimes yields flood run-off during a sudden thaw, but ordinarily absorbs all the precipitation falling upon it.

The streams which drain the mountain canyons increase in size from their source to the point where they emerge onto the alluvial slopes, and at this point their flow represents the difference between precipitation upon their catchment basins and evaporation. From here on, however, there are persistent losses by evaporation and by seepage into the porous formation of the valley fill. Careful measurements of 9 streams near Independence have shown that on the average *only 65 per cent of the water appearing at the mouth of canyons reaches a point one-half a mile west of the grass lands of the valley floor and that but 15 per cent reaches Owens River.* Between the first 2 points the evaporation loss is too small to consider, but in the valley floor where the water is used wastefully in irrigation it probably amounts to 30 or 35 per cent of the flow from the mountains. Therefore, in the region near Independence 50 per cent of the yield of these drainage areas is lost by seepage, about 35 per cent by immediate evaporation, and 15 per cent reaches Owens River.

The precipitation upon the alluvial slopes, although it does not appear on the surface, is not a loss, since probably 80 per cent of it sinks into the porous formation on which it falls, and together with the losses from stream channels percolates slowly eastward to join the great body of underground water beneath the valley floor.

The problem which then presented itself in the course of our study was: What becomes of the great volume of water which disappears into the valley fill? Luckily the valley is intersected at two places by rock ridges extending eastward from the base of the Sierra almost to the edge of the alluvial slopes fringing the Inyo Mountains. The cross-sectional area of the valley fill is greatly contracted at these points and much of the underflow southward is forced to the surface and appears in the channel of Owens River. It is thus possible to isolate sections of the valley and by careful measurement determine quantitatively the total volume of water entering the basin and a portion of the volume leaving it. Since the volume still unaccounted for could not accumulate indefinitely without appearing somewhere, there must be a definite outlet for it.

The significance of the meadow lands and the alkali in the valley floor then become apparent. *The water unaccounted for was passing into the atmosphere by evaporation and transpiration from the meadow land.* The fluctuation of the ground water surface represented the variation in the evaporation rate during the year, and the alkali deposit was left behind by the evaporated water. If spread over the 43 square miles of meadow lands in the basin in which Independence is located, the volume of water unaccounted for during one year would have a depth of 3.1 feet, or 56 per cent of the depth of evaporation from an exposed water surface in this region.

To test these conclusions a comprehensive series of tank experiments was planned for the purpose of measuring evaporation losses from soil and meadow grass. These experiments are still in progress, but they already show that, where the water-level is not more than 3 feet nor less than 1 foot below the surface, *that a depth of evaporation of about 80 per cent of that from an exposed water surface can be expected.* The experiments are to be carried on during the coming year for depths greater than 3 feet and under a variety of conditions, so that the results may be reliable as far as is possible under artificial conditions.

There is an interesting practical application of these ideas to the conservation of underground water supplies, which has been suggested by Mr. Mulholland. As noted above, *grasses do not grow, nor is there any alkali deposit where the depth to water exceeds 8 or 9 feet,* and also it has been found that groundwater fluctuations do not here obey the periodic law. It is therefore reasonable to conclude that no appreciable evaporation occurs from soil under such conditions. The lowering of the ground-water level under the meadow land by pumped or flowing wells in large numbers will eventually bring about a condition where evaporation losses will cease. The water that formerly was lost is then available for pumping, and further lowering of the water level will cease unless the pumpage exceeds the inflow into the underground reservoir. It has occurred to the writer that agricultural regions affected by rising ground water and alkali would do well to make a careful study of the local conditions, with these ideas in view.

THE OWENS VALLEY AND THE LOS ANGELES AQUEDUCT.

By A. B. WOLLABER, U. S. Weather Bureau, Los Angeles, Cal.

It is probable that no greater feat of engineering skill was ever attempted by a municipality than that now being carried on by the City of Los Angeles in bringing water from the Owens River, over rough mountains and a vast desert region, a distance of over 200 miles, to the storage reservoirs which will be located in the San Fernando Valley a few miles from the city.

The great Los Angeles Aqueduct is being pushed to completion at an astonishingly rapid rate and the dream of those intrepid engineers, who have every confidence in the practicability of this gigantic undertaking, is fast becoming a reality. The immensity of the project renders it of more than passing interest to the country as a whole, and it will no doubt prove of interest to the readers of the MONTHLY WEATHER REVIEW to know something of this important work, as well as to know something of the hydrological and climatological conditions covering the region whence this water supply is to be taken.

The rights and grants given to the Pueblo of Los Angeles by Spain as early as 1781 included a right to take and use all water of a stream that has since become known as the Los Angeles River, and which forms the outlet of a great subterranean reservoir known as the San Fernando Valley. These rights descended to the present city. It became apparent some years ago that the amount of water to be obtained through the medium of the Los Angeles River would soon be insufficient for the needs of the city, and a careful investigation was made of the possibilities for further water development in the neighborhood. These investigations disclosed the fact that it was practically useless to try to develop more water in this section, as the quantity obtainable would not meet the demands of future years, besides to draw further on the natural resources here would prove a serious menace to the future of the rich agricultural sections outside the city. It was finally determined that the only